Integrating Geodata Infrastructures from the Ground Up

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Abstract

The National Spatial Data Infrastructure (NSDI) requires vertical integration. Multiple levels of government produce geodata at multiple levels of resolution, multiple levels of attribution, differing update cycles, and differing levels of cost. The chronology of developments in data production and application shows the success of varying roles of local, regional, state, and national governments to provide data to their immediate constituents. The same chronology shows the lack of success in integrating geographic information between government levels. This lack of vertical integration forms a major impediment to a fully robust NSDI. This paper concludes by presenting a proposal for vertical integration, currently under discussion in Kentucky, to serve as a model for other state and local stakeholders to consider.

Introduction

The National Spatial Data Infrastructure (NSDI) is part of the evolving National Information Infrastructure, designed to provide citizen access to geospatial information (also called geospatial data or geodata). Geospatial information is distinguished from other spatial information (architectural blueprints or medical imaging products, for example) in that items are georeferenced to the Earth by direct means (coordinates) or indirect means (place-names, street addresses, topological relations, or verbal descriptions). Access to accurate and current geospatial information can foster sound decision-making within a "community" by allowing government to concentrate on its missions rather than on production and recreation of maps. A "community" may be contiguous, as for example a neighborhood, a county, or a nation. It may be diffuse, like the community of American wheat farmers, the community of inner city K-12 teachers, or the community of citizens opposed to nuclear power.

Development of new infrastructures is often driven by national-level needs. Fifty years ago, the problems of increasing automobile and truck transportation, paired with the federal government's interest in improving national defense preparations, led President Eisenhower to sign the Federal Highway Act of 1956. The resulting infrastructure, the Interstate Highway system, supported development of an organized trucking industry, which in turn shifted economic markets away from railroads. More recently, the desire to speed business transactions, coupled with the federal government's interest in an electronic communication system that would survive nuclear war, led to construction of the Internet. The economic results include lightning-fast computerized stock and bond trading and a shift in business transactions away from physical and verbal correspondence to electronic mail.

As telecommunications and highway networks provide a physical infrastructure, geospatial data provide an information infrastructure. The geographic information community faces a challenge different from either Interstate or Internet infrastructure builders. Myriad, independently evolved infrastructures already exist at local, regional, state, and national levels. Further, national agencies (mostly of the Federal government, but also various non-profit organizations, should be included) often work as key stakeholders with local geospatial data. The current situation is not one of building an infrastructure from scratch. The NSDI needs to integrate disparate infrastructures horizontally and vertically. This paper presents the rationale for enhancing efforts to promote vertical integration between different levels of government. It ends with the presentation of the Commonwealth of Kentucky's proposal to enhance vertical integration between federal, state, and local agencies through agreements, partnerships, and research.

Data Sharing Incentives

Geospatial data are expensive to collect, to update, and to maintain. The first premise of sharing geospatial data is that geospatial data have inherent social value, a functions of the cost to create, archive, distribute, and process data (i.e., to use the data in an application). A second premise for sharing data relates to the costs associated from *not* having access to others' data. Decisions made locally will often effect higher levels of community. A third premise for data sharing is that integrating existing data into a vertical infrastructure eases the flow from data production to data use. Update costs are highest locally, as are consequences for data misuse (or abuse). Through local stewardship, benefits of using geospatial data accrue at all levels of use, for local users, users in adjacent communities, and federal level policy-makers. To achieve such benefits requires that data be integrated to provide telescopic views of local data, to discover accurate and current data at all levels of resolution. Federated groups have been and continue to be the most viable approach. Organizational, legal, and economic issues continue to impede vertical integration in heterogeneous data sharing environments (Burrough and Masser, 1997; Masser, 1998; Masser and Campbell, 1994; Nedovic-Budic, 1995; Onsrud and Rushton, 1995). Vertical integration is the only practical approach for building a vigorous NSDI.

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Photogrammetric Engineering & Remote Sensing
Vol. 65, No. 11, November 1999, pp. 1287-1291.

0099-1112/99/6511–1287$3.00/0

Data Integration and the NSDI

An interesting insight into the stability of infrastructures is provided by Warneke (1993), who comments that levels of vertical coordination show the degree to which an infrastructure is maturing and becoming acknowledged by communities that rely upon it. She adds that horizontal integration often pre-dates evidence of vertical coordination. When horizontal integration does not occur, the stability of the infrastructure is compromised. As difficult as horizontal integration may be, it seems that vertical integration is even more challenging. Vertical integration also depends upon important technological advances.

Land records integration intended to foster the creation of a single multipurpose cadastre (or Multipurpose Land Information System, MPLIS) for all agencies in a local region (National Research Council, 1980) is an important touchstone. Local and regional governments have and still play a major role in developing and promoting MPLIS (Niemann, 1984).

The MPLIS was intended to harness local data production capabilities into a system that would be accessible to all agencies. Nevertheless, institutional problems obstructed full implementation. Political and administrative agencies within a city or county were often unable to agree upon a single computing platform, data dictionary, or mapping application software (Obermeyer and Pinto, 1994). Practitioners laid out various pragmatic strategies for coping with these problems, such as project champions, cost sharing programs, cost benefit analysis, etc. (Aronoff, 1989; Somers, 1998). Organizational issues such as lack of agreement, institutional obstructions, and agency friction are significant impediments to MPLIS projects.

Concurrently, the federal government was automating significant components of mandated activities. The 1980s proved to be a time of intense federal effort to achieve horizontal data integration, culminating in the establishment of a nationwide Spatial Data Transfer Standard (SDTS) as a Federal Information Processing Standard (NIST (National Institute of Standards), 1992). In 1990, the OMB revised Circular A-16 to expand the scope of digital data coordination beyond the U.S. Geological Survey (USGS) and establish the Federal Geographic Data Committee (FGDC) (**www.fgdc.gov**). Moving the coordination activity from the shoulders of a single agency to the collective responsibility of all federal data producers broadened the circle of stewardship, focusing attention on horizontal integration. By 1992, institutional mechanisms for federal level infrastructure cooperation were in place.

President Clinton's Executive Order 12906 (Clinton, 1994) catalyzed NSDI in the highest levels of government with its stated intention "to support public and private sector applications of geospatial data in such areas as transportation, community development, agriculture, emergency response, environmental management, and information technology." The Executive Order described activities that were to be undertaken to promote data sharing between federal, state, and local governments; citizens; private sector organizations; and academia. The following year, a Metadata Content Standard (FGDC, 1995; FGDC, 1997) established standards for describing data sets that would be exchanged. By the end of the decade, the federal level of NSDI was seeing positive results from horizontal integration (National Research Council, 1993).

Ancillary activities initiated by the USGS provided a first attempt at fostering participation from non-federal communities in the federal coordination process. In 1987, the USGS commissioned the National Research Council (NRC) to appoint a Mapping Science Committee (MSC), an external source for critique and advice on federal mapping activities. The Mapping Science Committee members include representation from state and local governments, non-governmental organizations (NGOs), the private sector, and academic institutions. The committee has published several monographs arguing the merits of coordinating a spatial data infrastructure and to foster dialog on continued integration, among all levels of constituents (National Research Council, 1993; National Research Council, 1994; National Research Council, 1995; National Research Council, 1997; National Research Council, 1999).

The federal efforts fostered horizontal integration as well. Involvement of state governments with federal-state partnerships was only encouraged for specific programs with specific states, as a cost-saving measure for both sides (National Research Council, 1994). However, by the early 1990s, there was little integration of state and local data production into NSDI. From the perspective of governments other than federal, the federal-centric NSDI model provides data at too coarse a spatial resolution and relies on standards developed and imposed top-down. Partnering opportunities were offered on an equal-share basis, but the product specifications did not fully correspond to local needs. Because they did not serve local constituencies who had the greatest commitment to collect and maintain detailed and current geospatial information, local and state stakeholders who felt disenfranchised began to build data infrastructures to meet local needs. However, these did not integrate easily with adjacent or with higher level jurisdictions. Thus, the institutional stage was set against easy vertical integration, because individual integration processes had to accommodate unique data production scenarios.

A Model for Vertical Integration and Data Sharing

The NSDI involves multiple producers, multiple users, and various geospatial data products. Local data production may occur within or between counties, within or between municipalities, and even within or between neighborhoods. An example of the latter would be a local urban neighborhood adjacent to a large university campus, wherein the two communities agree to collaborate on monitoring crimes related to alcohol abuse on and off campus.

Although the spatial footprint of a county or neighborhood is geographically smaller than state or nation, local geospatial data are the most expensive to produce. Data production at the local level requires the finest resolution, the highest positional accuracy, the highest level of attribute detail, and the most frequent update cycle. Levels of commitment to data accuracy and currency are highest at the local level because people are vested in their immediate surroundings. As their knowledge of immediate surroundings is detailed, they detect errors and omissions more readily, leading to the most accurate information.

In principle, the NSDI operates as an institution. The institutional mission is to create and disseminate geospatial information products to the largest possible constituency for the lowest possible overall costs. The institution is characterized by activities at many levels, including local, regional, state, and national governance bodies. Stakeholders may contribute at more than one level; for example, a state GIS coordinator may also be a member of a national organization, such as the MSC. The structure of the NSDI institution may be thought of as a geometric object, as in Figure 1.

The top of the cone represents data products created by federal and national level agencies. These products are created in response to national initiatives, and programs involving cross-state activities. Geospatial data at this level are characterized by minimal attributes, relatively coarse resolution, and the lowest resource outlays of any level in the cone. Moving down the cone to the levels of state data production activities, products are created in response to various activities within states, with adjacent states, or in support of county level activities. Increased levels of detail raise costs considerably. In 1988, federal and state government outlays for geospatial data production were about 100 million dollars. Local government outlays were about six times that amount (National Academy of Public Administration, 1998).

Figure 1. A structural model of geospatial data integration.

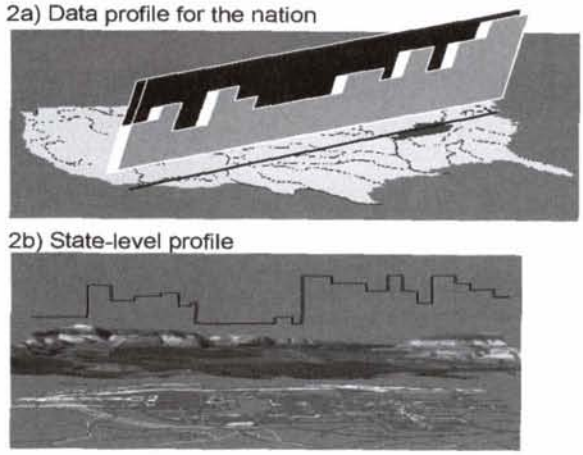

Figure 2. Data availability is not uniform (state landscape courtesy of ESRI, Inc.)

Figure 1 presents a structural model of geospatial products created and maintained by agencies at various levels in the NSDI institution. For purposes of this article, we will not distinguish these products as data, information, knowledge, or wisdom. Neither should the reader infer that products produced at the bottom are data, and those produced at the top are wisdom. The implication of the model is that horizontal slices through the cone represent data producers at local, regional, state, and federal levels. Organizations and agencies at each level can produce geospatial products of utility not only to their level, but for levels above and below them as well.

Technical Impediments to Vertical Integration

In theory, products at a lower level in Figure 1 could be simplified or generalized to fill gaps in the products at higher levels. Herein lie major technical problems impeding vertical data integration. At present, algorithms for merging data at multiple levels of resolution are not fully operational. This is particularly true for attribute generalization. Attribute hierarchies do not nest cleanly outside the original design. For example, differences in vegetation classes, of ecology land-cover types, or of soils inclusions demonstrate this point. A single unified hierarchy will not meet all possible applications and account for different semantics at all levels in the cone.

The assumption in the cone model is that geospatial data are comprehensive. In theory, one could place the cone over any portion of the country, and find complete, accurate, and current geospatial data sets compiled for the entire portion, at multiple levels of resolution. In practice, this is not so. Figure 2 demonstrates variations in data availability at any two levels, say national and one state level. Some parts of the country are mapped more intensively than others, more frequently, or have more data products available. The national level data product profile varies state by state, giving the impression that the state availability profile is uniform. Profiles for an individual state demonstrate this is not so. That is, some parts of each state are also mapped more intensively than others. Reasons for this may relate to pockets of natural resources, sites of sudden demographic growth, or areas of high risk for natural hazards.

The lack of uniform data coverage impacts vertical integration. If data do not exist at a lower cone level, are out of date, or are attributed differently, data sets cannot be incorporated to higher levels in the cone. This can result in unresolvable semantic discrepancies, positional accuracy diminishing the quality of the combined data, unpredictable risks, and unreliable decision support. The cone is heterogeneous, not monolithic.

Another pressing technical impediment is presented by the need for data certification. With Internet technologies for data dissemination, multiple sources of geospatial data have emerged. A functional multi-source and multi-resolution data foundation cannot be stabilized based on data of unknown compilation dates, unknown processing lineage, or unknown data quality descriptions. A single uniform data format need not be adopted, but, rather, unified plans for data certification should be adopted as a prelude to data sharing and interoperability. The length of time required to overcome these and other technical impediments depends on the extent to which local governing bodies can be supported in maintaining high quality local level data. A related pressing need is for research funds to derive data fusion and data merging algorithms.

Institutional Impediments to Vertical Integration

Information systems literature on institutional factors points to five factors that impact institutional data sharing. Entrenched bureaucratic practices enforce inertia and impair development of novel operating procedures (Kraemer and King, 1986; Pinto and Azad, 1994). Lack of cross-functional cooperation isolates individuals within the institution as a whole. The type of organizational structure may impede rather than foster opportunities for cooperation (Campbell and Masser, 1995; Masser and Campbell, 1994). The production of geographic information is arguably a process of corporate culture, which is a social construction by itself (Harvey and Chrisman, 1998). Fifth, the political environment will advocate that particular practices be adopted either *de juris* or *de facto*, and the economic environment will constrain practices that do not return a cost benefit or other profit (Onsrud and Rushton, 1995).

Organizational issues remain among the most pressing impediments to information exchange and sharing (Nedovic-Budic, 1997). Evans and Ferreira (1995) point to the need for building a "spatial data infrastructure" that recognizes that organizational change can have a greater impact than will technology itself. The argument in much of the literature is that geographically referenced data are always useful for other groups in many ways.

Whether institutional inertia obscures more trenchant obstacles is difficult to discern without documentation from several ongoing case studies. Five community-level projects are currently funded by FGDC that should provide valuable

insights (see **http://www.fgdc.gov**). Each project demonstrates a federal department (Interior, Commerce, Justice, Agriculture) partnering with a community. The partnerships are based upon moving data vertically between different levels of government. Additional incentives must be put in place to move vertical data sharing from the "special project" scenario to a fully operational activity within all sectors of NSDI.

The Kentucky Proposal

Like other states, Kentucky is developing a Data Sharing Consortium involving the state's chief information officer, Office of GIS, Geographic Information Advisory Committee, Commonwealth Cabinets (Agriculture, Economic Development, Natural Resources, and others), regional, county, and municipal governments, nonprofit and educational institutions, the private sector, and Federal agencies. The Kentucky Office of GIS has coordinated these activities since 1994 through legislation that provides for general fund access and the development of public-private partnerships to arrange for the most optimal cost-sharing and data-sharing arrangements. The general GIS community (towns, counties, area development districts) is involved through shared responsibilities for geospatial data, products, incentives, services, and benefits. The Consortium links these stakeholders through agreements, partnerships, and research.

Kentucky's consortium is at the cusp of new organizational approaches to vertical integration that FGDC activities have stimulated. In this approach, the services that stakeholders provide depend on the mission of specific agencies. Through their roles as data creators, integrators, and maintainers, they steward geospatial data products and provide data to other communities statewide. The Kentucky State Office of GIS coordinates and oversees other roles, and serves as the primary conduit for federal-to-state, state-to-community, and federal-to-community level GIS data sharing.

Individual agreements form a fundamental part of the consortium. Stakeholders of the Kentucky Consortium agree to specific responsibilities. One responsibility is to contribute data to the State GIS Clearinghouse, and to undertake responsibility for data maintenance, improvements, and timely update. Members agree to conform to standards and share their geospatial data through the clearinghouse and respond to other member's requests for data. They agree not to redistribute another member's data, but refer requests directly to that member. The theme Authorities verify accuracy, completeness, precision, and currency of a specific theme. The Consortium approach to vertical integration presents issues that effect vertical integration in terms of institutional settings and technical demands. These issues include benefits, standards, policy and legislation, incentives to participate, funding, and research.

Benefits

The Commonwealth of Kentucky benefits from a data sharing consortium in several ways. The obvious benefit to citizens and agencies is through a more cost-efficient use of taxpayer resources. The most evident resource savings is derived from creating good data once, and avoiding costs in creating duplicate data. This also fosters subsequent application development because the time and expense of basic data development is avoided.

A second benefit relates to data accuracy. Agencies are required by their mandates to maintain accurate and current data. Once basemap data are available and in common use by the community, errors can be corrected during use. With the advent of the Internet, local knowledge becomes a powerful updating mechanism that enhances decentralized collection and maintenance of information. The strategy is to have users notify the Consortium when data errors are detected. Users are vested in correcting the statewide representation of their locale, as described above. This provides an excellent example of the democratization of geographic information.

Standards

The most difficult first step to establish a data sharing consortium is the creation of rules and their acceptance by partners in standards for automation, attribution, and exchange. A lack of a consensus was cited above as a prime reason for the failure of the early attempts to consolidate the Multipurpose Cadastre, in the early 1980s. The establishment of standards for data inclusion, data themes, coordinate systems, product specification, and data documentation from the local level up is necessary. The FGDC theme standards at least give states a place to start the adoption process for rules applicable to intrastate data creation, use, and cost sharing.

Policy and Legislation

Policy and legislation must be crafted and put into practice to govern data access, data distribution, service pricing, data pricing, data sharing, integration, and verification. Without strong policy, the integration of geospatial data remains tied to personalities rather than institutionalized into a governance structure. The policy requires a framework within which GIS activities can flourish from the coordinating agency to the field and back, not an inflexible structure that acts as a stovepipe. The policy must be developed with full realization that the NSDI is, *in fact*, being built from the ground up, not from the top down. These sections contain examples from Kentucky that illustrate policy and legislative dimensions for promoting vertical integration.

Incentives

The best incentive that currently motivates Consortium participation is the wealth of available data. At present, geospatial data that are available for Kentucky include digital orthophoto quadrangles (DOQ), 30-meter digital elevation models (DEM), statewide hydrography at 1:24,000-scale, and 1:24,000-scale transportation.

A second incentive is that by joining, members' data products gain instant statewide visibility. Users can browse a single centralized data repository knowing that its contents are accurate and validated by a specific Consortium member.

A third incentive involves several pilot projects. By joining, members gain opportunities to see pilot projects funded for their area. By participating in these projects, various state, county, and local agencies contribute to the statewide infrastructure and simultaneously upgrade their local data holdings. Several projects are currently underway. One pilot project is the production of 10-meter hydrology-corrected DEMs for the State. In another collaboration with the federal government, a statewide Hydrology Data Set Project is underway with the USGS. A third pilot project in the planning stage will initiate public/private partnerships to produce address-geocoded street-centerline data that match the Kentucky DOQs.

The building of consortiums takes advantage of economies of scale in this process and begins cost reductions through multiple use of data. Pooling resources is one of the most viable ways to eliminate redundancy, reduce effort, and reduce costs. In Kentucky, the basemap was built with general funds and federal match funds, setting the stage for further cooperative funding arrangements. While the basemap and other framework data are funded in this manner, subscriptions promise to be viable means of securing funding for other data sets. This is an issue currently being explored in Kentucky.

Research

The recent National Academy of Public Administration (1998) publication states that "Priorities for research should include, but not be limited to, programs to develop (1) practical generalization software to translate between scales; (2) techniques for utilizing satellite imagery to enable rapid updating of GI data

files and maximum analytical use of this new source of massive amounts of GI without overwhelming the system; (3) easy-to-use automated techniques for updating base data with current transaction data; and (4) software for merging and harmonizing geographic data files from diverse sources." The national research agenda correlates well with other vertical integration issues identified here.

Summary and Recommendations

This paper illustrates institutional and relevant technical issues that must be resolved to facilitate vertical integration of local geospatial data infrastructures into the NSDI. We represent the NSDI as a cone whose breadth reflects the volume and detail of the geospatial data used to carry out government mandates. The vertical dimension of the cone indicates local, regional, and national level governing bodies. Vertical integration links these levels and assures a stable infrastructure.

The NSDI is conceptually solid. Initiatives that vertically link local government activities insure the NSDI as the geographic information backbone of the nation. The complexity of public administration requires templates for action that integrate all levels. Vertical links can be established by flexible approaches such as joint funding, cost sharing, subscriptions, and work sharing. The key point is to focus incentives on partnering opportunities that target local governmental agencies and build on local standards in deference to top-down models. Data certification is a key component in developing approaches that reflect the differing data production situations at local levels. Local needs must be met to motivate local participation. The resulting agreements must be augmented by flexible conversion strategies that support different attribute schemes and shareable data models that are flexible and robust (Vckovski, 1998).

Not only data, but also people, institutions, and technology make up the NSDI. Data integration and data sharing are prerequisite to other types of vertical flows through the NSDI cone. Interaction must drift down to state, municipalities, and counties who are in touch with their localities and have key investments to maintain. For governmental IT practices, a sound econometric model of NSDI has yet to be developed along with a framework of instruments for institutional agreements that will forge vertical integration. Technical solutions to fuse data at multiple resolutions, multiple dates of compilation, and multiple levels of completeness must be implemented, and their results must be validated for semantic accuracy.

Without additional resources going to state and local agencies, there is little chance that activities at the base of the cone model will be sufficient to ensure a stable foundation for the NSDI. Data sharing, exchange, integration, and interoperability can improve infrastructure stability and reduce costs. Without incentives, however, the best intended technical solution remains on the shelf, or is passed over in favor of re-engineered horizontal integration that fails to realize the NSDI potential.

Acknowledgments

We wish to thank Larry Sugarbaker for pointing out that national is a more fitting term than federal to describe the top level of the cone. The comments of two anonymous reviewers were also a substantial help in preparing this paper.

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